

Aging affects attunement in perceiving length by dynamic touch

Rob Withagen · Simone R. Caljouw

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Abstract Earlier studies have revealed age-dependent differences in perception by dynamic touch. In the present study, we examined whether the capacity to learn deteriorates with aging. Adopting an ecological approach to learning, the authors examined the process of attunement—that is, the changes in what informational variable is exploited. Young and elderly adults were trained to perceive the lengths of unseen, handheld rods. It was found that the capacity to attune declines with aging: Contrary to the young adults, the elderly proved unsuccessful in learning to detect the specifying informational variables. The fact that aging affects the capacity to attune sets a new line of research in the study of perception and perceptual-motor skills of elderly. The authors discuss the implications of their findings for the ongoing discussions on the ecological approach to learning.

Keywords Aging · Attunement · Dynamic touch · Ecological psychology

Over the last decade, several studies have examined the effects of aging on dynamic touch (Carello, Thuot, & Turvey, 2000; Chang, Wade, Stoffregen, & Ho, 2008). Dynamic touch is the ability to perceive object properties by holding the object in the hand and wielding it. Ever since the pioneering study of Solomon and Turvey (1988), this perceptual capacity has been studied extensively (e.g., Carello & Turvey, 2004; Turvey, 1996; Turvey & Carello,

1995; Wagman & Carello, 2003). By wielding an unseen object, participants have been found to be capable of perceiving many of its properties—for example, its length, form, mass, hammer-with-ability, and poke-with-ability. In their study of the effects of aging on dynamic touch, Carello et al. investigated the ability to perceive the sweet spot of a tennis racket—that is, the best place on the racket to hit a ball. Although the sensitivity of the skin degrades with aging (e.g., Kenshalo, 1986; Stevens, 1992), Carello et al. found that both young and elderly adults (62–89 years of age) can perceive the sweet spot of a racket. However, their judgments differ slightly in accuracy; in general, the elderly perceived the sweet spot to be closer to the hand than did the young adults. Chang et al. examined the ability to perceive length and also reported differences between the elderly and undergraduates. However, crossing the effects of age and experience, they found that the differences are attributable primarily to experience and not to age itself: Experience in playing a racket sport was more influential on the length judgments than was age.

The fact that experience (and not age) proves critical in the perceptual performances does not mean that perceptual capacities do not deteriorate with aging. In fact, it might be that the elderly do not learn as well and as quickly as younger adults. They might need more feedback to master a perceptual skill. Earlier studies of motor skills have shown that the elderly are still capable of learning new tasks. However, some studies have found that their learning process is significantly slower than that of young adults (e.g., Fernández-Ruiz, Hall, Vergara, & Díaz, 2000), or that the learning effects are less pronounced (e.g., Bock, 2005; Bock & Girgenrath, 2006). It is not unlikely that this degradation can also be observed in a perceptual task. Recently, Withagen and van Wermeskerken (2009)

R. Withagen (✉) · S. R. Caljouw
Center for Human Movement Sciences, University Medical
Center Groningen, University of Groningen,
P.O. Box, 196, 9700AD Groningen, The Netherlands
e-mail: R.G.Withagen@med.umcg.nl

suggested that perceivers vary in their perceptual learning capacities. Using the paradigm of dynamic touch, they studied the learning curves of a considerable number of participants and reported large individual differences. Participants varied in whether, when, and how they responded to the feedback. This variation was observed when participants were to judge length while wielding the rod (Withagen & van Wermeskerken, 2009) and also while holding the rod horizontally (Menger & Withagen, 2009). On the basis of their findings, Withagen and van Wermeskerken concluded that participants vary in their abilities to take advantage of feedback information. Up to this point, it is unclear what happens to these learning capacities when people grow older. Do these capacities remain intact, or do they decline with aging? This question will be addressed in the present study.

As in other studies of dynamic touch, we adopted an ecological perspective to study this perceptual capacity. The Gibsons (J.J. Gibson & E.J. Gibson, 1955) argued that perceptual learning is a process of differentiation: The perceiver learns to exploit the right informational variable in the ambient array. The underlying idea of this theory of learning is that perceptual variables differ in their degree of usefulness. This means that a perceiver can improve the accuracy of the judgment by learning to rely on the more useful variables. This process has been termed *the education of attention* or *attunement* and has been observed in many paradigms (for overviews, see Fajen, 2005; Jacobs & Michaels, 2007; Withagen & van der Kamp, 2010), one of which is dynamic touch (e.g., Arzamarski, Isenhower, Kay, Turvey, & Michaels, 2010; Cabe, 2010; Jacobs, Silva, & Calvo, 2009; Menger & Withagen, 2009; Michaels, Arzamarski, Isenhower, & Jacobs, 2008; Wagman, Shockley, Riley, & Turvey, 2001; Withagen & Michaels, 2005; Withagen & van Wermeskerken, 2009). Several studies have revealed that novice perceivers generally rely on the major principal moment of inertia (I_1) and/or static moment (M) to perceive rod length by dynamic touch (e.g., Kingma, van de Langenberg, & Beek, 2004; Solomon & Turvey, 1988; van de Langenberg, Kingma, & Beek, 2006). These mechanical variables relate ambiguously to the lengths of homogeneous rods and can therefore be qualified as nonspecifying variables. After all, both I_1 and M are functions of the rod's length, material density, and diameter. This means that rods of equal length but made of different materials can differ in both I_1 and M , and that rods that are identical in these mechanical variables can differ in length. Thus, relying on these variables results in inaccuracies in the perceptual judgment. However, provided with feedback, participants have been found to attune to variables that are specific to length. Any ratio of two moments of mass distribution relates one-to-one to the length of homogeneous rods (see Menger & Withagen, 2009; Withagen & van

Wermeskerken, 2009). Consider, for instance, the ratio of M and mass

$$\frac{M}{m} = \frac{m \cdot L/2}{m} \quad (1)$$

where m is mass and L is length. The mass cancels, rendering the ratio of M to m to be a single-valued function of length. Note that although a specifying variable relates one-to-one to the to-be-perceived property, this relation does not have to be a linear mapping. Another mechanical variable that specifies the length of a homogeneous rod, for example, is the ratio of I_1 to m

$$\frac{I_1}{m} = \frac{\frac{1}{3} \cdot m \cdot l^2}{m} \quad (2)$$

Because the mass cancels, the ratio of I_1 to m is also related one-to-one to length, but it increases as the cube of length. Earlier studies have revealed that after feedback, participants can learn to rely on a specifying variable to perceive length (Menger & Withagen, 2009; Withagen & Michaels, 2005; Withagen & van Wermeskerken, 2009). However, as mentioned earlier, perceivers have been found to vary in their capacity to do so (Menger & Withagen, 2009; Withagen & van Wermeskerken, 2009). Although the previous studies of aging and dynamic touch have compared experienced perceivers and novices (Carello et al., 2000; Chang et al., 2008), they have not examined the process of attunement. However, to gain insight into whether the capacity to learn declines with aging, a study of this process is in order.

The present experiment

The aim of the experiment was to examine whether the perceptual learning capacities deteriorate with aging. To this end, we compared the learning performances of young adults with those of the elderly. Participants were trained to perceive the lengths of unseen, homogeneous rods. We used a pretest-feedback–posttest-retention test design. In the test phases, the participants were to judge the length of the handheld rod. In the feedback phases, the participants received visual information about the length after they had made the judgment. As far as we know, earlier ecological studies of perceptual learning have not conducted a retention test. However, such a test provides insight into whether the induced changes in variable use are relatively permanent.

Method

Participants By way of informed consent, 10 undergraduates and nine older adults volunteered to participate in the

experiment. The undergraduates ranged in age from 20 to 30 years (mean age 23.6, $SD = 3.1$). There were four females and six males; two participants were left-handed, and eight were right-handed. The older adults ranged in age from 59 to 81 years (mean age = 65.8, $SD = 6.3$). There were three females and six males, all of them being right-handed.

Materials As in earlier studies of learning to perceive length by dynamic touch (Menger & Withagen, 2009; Withagen & Michaels, 2005), we used two distinct sets of rods. To prevent participants from simply learning to identify individual rods, one set was used in the feedback blocks, and the other set in the test blocks. Each set consisted of 13 rods made from hollow carbon pipes or solid wood, steel, or aluminum. The rods differed in length, diameter, and material (see the Appendix). Identical 11.5-cm plastic handles were affixed to each rod, preventing the participants from feeling the material the rod was made of or its diameter. In choosing the collection of rods, we were primarily interested in the mechanical variables M and I_l . As mentioned in the introduction, novice perceivers tend to rely on these nonspecifying variables. We chose the collections so that for each set, actual length correlated weakly with the nonspecifying variables I_l and M (see Table 1). The reason for this was two-fold. First, low correlations made it easier to determine whether participants detected a specifying or a nonspecifying mechanical variable. After all, low correlations between actual length and I_l and M mean that the specifying and nonspecifying variables are disentangled. Second, in the feedback phases, we intended to induce the process of attunement. Earlier studies have revealed that this process is more likely to occur if the variable that participants initially detect correlates weakly with the to-be-perceived property (Jacobs, Runeson, & Michaels, 2001; Michaels et al., 2008; Withagen & Michaels, 2005). After all, reliance on such a variable results in poor performance, informing the participants in the feedback phase that a change in what information is exploited is needed.

Table 1 The correlations between the logarithms of the candidate variables and actual length

	Length	I_l	M
Test rod set			
Length	-	.375	.002
I_l	-	-	.928
M	-	-	-
Feedback rod set			
Length	-	.185	-.138
I_l	-	-	.948
M	-	-	-

Design and procedure The experiment consisted of a pretest, four feedback blocks, a posttest, and a retention test. We divided the experiment into three stages that were carried out on separate days. The first stage consisted of a pretest and two feedback blocks, the second stage of two feedback blocks followed by a posttest. Except for one participant, these stages were carried out on consecutive days. The retention test was conducted to test whether the induced changes were relatively permanent. This test was carried out minimally 9 days after the posttest. Two older adults did not participate in this test because they were unable to come to the lab. As in earlier studies of length perception by dynamic touch (e.g., Kingma et al., 2004; Solomon & Turvey, 1988; Withagen & Michaels, 2005), participants were seated on a stool with their right forearm on an armrest. An opaque curtain between the stool and armrest prevented them from seeing the handheld rod. In front of the participant, there was a rail with a small planar surface attached. The participant could move this surface along a rail by rotating a wheel with the left hand. The participant was to position the surface so that it coincided with the perceived distal end of the handheld rod. The distance between the surface and the participant's hand was defined as perceived length.

Each block consisted of 26 trials. The rods of a certain set were offered twice, and the order of presentation was randomized. Because changes in information usage have proved to be accompanied by changes in the wielding behavior (cf. Arzamarski et al., 2010; Michaels, Weier, & Harrison, 2007; Riley, Wagman, Santana, Carello, & Turvey, 2002), we did not impose many restrictions on the exploratory behavior. As in earlier studies of learning in dynamic touch (Withagen & Michaels, 2005; Withagen & van Wermeskerken, 2009), the participants were allowed to hold the rod loosely in their hand and to wield it freely.¹

¹ One might wonder whether the mechanical variables can still be computed when the participants were allowed to hold the rod loosely in their hands. After all, the vast majority of studies of dynamic touch have computed the mechanical variables with respect to the wrist (i.e., the presumed rotation point) and have thereby assumed a constant distance between the proximal end of rod and the wrist (e.g., Carello et al., 2000; Riley et al., 2002; Solomon & Turvey, 1988). However, we follow van de Langenberg et al. (2006) in computing the mechanical variables with respect to the end of the rod (see also Withagen & Michaels, 2005; Withagen & van Wermeskerken, 2009). This means that a changing relation between the end of the rod and the wrist does not complicate the computation of the mechanical parameters. However, it also means that one should be careful in comparing our conclusions about which mechanical variables are exploited with findings reported in many previous studies of dynamic touch; indeed, as argued elsewhere (Withagen & Michaels, 2005, footnote 3), the values of mechanical variables differ when computed with respect to different points. However, the main aim of the present study is not to uncover what mechanical parameters are exploited. Instead, the main purpose is to study (variation in) the perceptual learning process, the improvements in the judgments of length that are the result of the exploitation of more useful mechanical variables.

However, they were to hold their thumb to the disk that separated the handle from the rod. Also, touching the curtain or the floor was prohibited. In the test phases, the participants were simply to estimate the length by positioning the planar surface so that it coincided with the perceived distance reachable with the handheld rod. In the feedback phases, the participants received visual information about the actual length of the rod. After the participants made the judgment by positioning the surface, they were allowed to touch the curtain with the rod. This touching led to a curtain displacement that provided visual information about the position of the distal end of the rod. Moreover, the distance between the curtain displacement (actual distance reachable) and the position of the planar surface (perceived distance reachable) informed the participants about the accuracy of their perceptual judgment. In addition, the touching of the curtain with the rod provided also some haptic feedback that has proved to be sufficient to improve length judgments by dynamic touch (Stephen & Arzamarski, 2009). In both the feedback phases and the test phases, the participants were to position the planar surface at the proximal end of the rail after each trial.

Results

We first tested whether the participants' length judgments were more closely tied to actual length after feedback. We computed the Pearson product-moment correlations between perceived length and actual length for each individual and each test phase. Figure 1 shows these correlations for both the elderly and the young adults in the pretest, posttest, and retention test.² A repeated measures ANOVA with test (pretest, posttest, retention test) as a within factor and age (young adults, elderly) as a between factor (the assumption of sphericity was not violated) revealed a significant main effect of age, $F(1, 15) = 7.02, p < .05$. This indicates that for the young adults, the correlation of perceived length and actual length was higher than that for the elderly. The significant main effect of test, $F(2, 15) = 5.13, p < .05$, showed that the correlations differed between the test phases. Post hoc tests (Tukey-Kramer) demonstrated significant differences between the pretest and the posttest, and between the pretest and the retention test ($\alpha < .05$). However, the absence of a significant interaction of Age \times Test ($p > .05$) showed that the changes in correlation were not significantly different for the young adults and the elderly.

² All averaging and statistical tests done on correlations used the correlations' z -transformation.

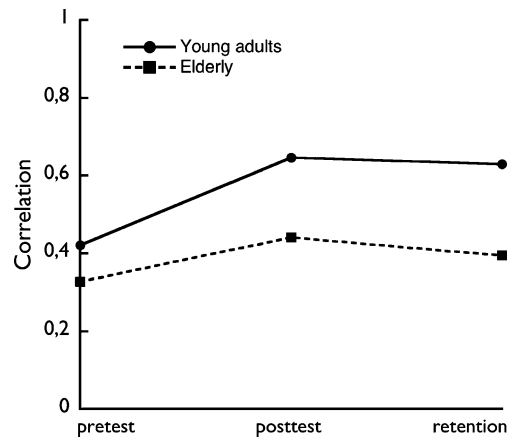


Fig. 1 The (absolute) correlations of perceived length and actual length in the pretest, posttest, and retention test. The dotted line depicts the elderly, the solid line the young adults

However, in and of itself, the previous analysis on the correlations did not show that the process of attunement had occurred. To determine whether it had, one would have to compare the correlation between perceived length and a specifying variable with the correlations between perceived length and the nonspecifying variables (see Withagen & Michaels, 2005). Because the relationship between actual length and I_l is a power function (i.e., for a homogeneous rod of some density, I_l increases as the cube of length), a logarithmic transformation of perceived length and I_l has proven to be required in computing their correlation (e.g., Solomon & Turvey, 1988; Turvey & Carello, 1995). Before applying the log transformation, we checked whether the residuals were congruent with a power function by graphing the data. The scatter plots of perceived length and the variable I_l revealed that a log–log transformation was justified. To make the analyses parallel, we also used the logarithms in computing the correlations between perceived length and the nonspecifying M .

The earlier computed correlation between perceived length and a specifying variable is equivalent to the correlation between perceived length and actual length. After all, by definition, a specifying variable relates one-to-one to the to-be-perceived property (either linearly or nonlinearly). As mentioned in the introduction, there are several mechanical variables that relate one-to-one to the length of homogeneous rods. Indeed, any ratio of two moments of mass distribution specifies length, implying that there is an infinite number of specifying mechanical variables available. Because these variables, by definition, correlate perfectly with each other, it is not possible to disentangle them in our analysis and thus to determine which of them is used. Hence, because we did not want to suggest that one of them is relied on, we used in our analyses the absolute correlation between perceived length and actual length, again using the logarithms of these

variables to make the analyses parallel. To determine whether the participants relied on a specifying or a nonspecifying variable, we tested whether the correlation of perceived length with actual length differed from the correlation of perceived length with the most highly correlated nonspecifying variable (Withagen & Michaels, 2005).

The young adults appeared to change in what variable they exploited over the course of the experiment (see Fig. 2). In the pretest, the correlation with I_1 was significantly higher than the correlation with actual length, $t(9) = 2.95$, $p < .05$, indicating that the young adults used a nonspecifying variable in their judgment of length. In the posttest, on the other hand, the correlation with actual length was significantly higher than the correlation with I_1 , the most highly correlated nonspecifying variable, $t(9) = 4.70$, $p < .01$. Apparently, the young adults learned to exploit a specifying variable during the feedback phase. Although in the retention test, perceived length was still most highly correlated with actual length, this correlation did not differ significantly from the correlation with I_1 ($p > .05$).

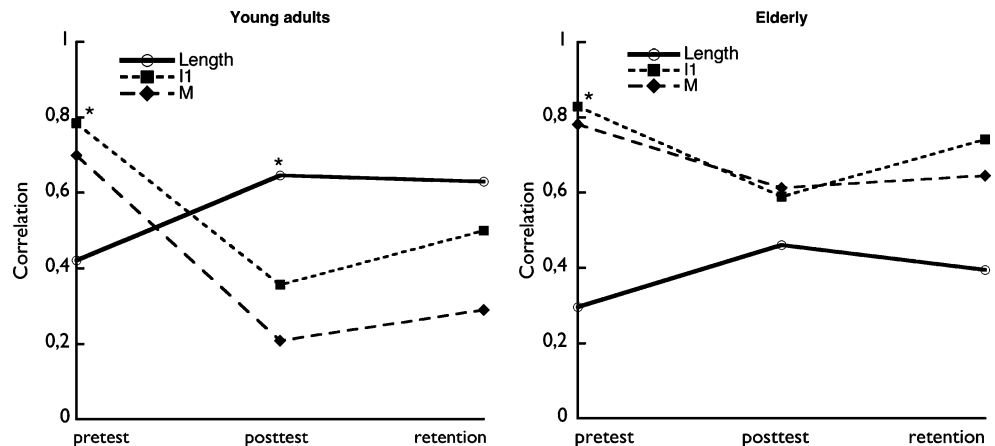
The elderly did not learn to rely on a specifying variable over the course of the experiment (see Fig. 2). In the pretest, they generally relied on a nonspecifying variable. The correlation with I_1 was significantly higher than the correlation with actual length, $t(9) = 8.59$, $p < .0001$. However, in the posttest and the retention test, they did not detect a specifying variable, nor did they continue to rely on the nonspecifying variable they initially exploited. In these two test phases, the correlations did not significantly differ from each other ($ps > .05$). Apparently, for the elderly, the feedback induced changes in perceptual performance. However, the relatively low correlations between perceived length and the nonspecifying variables in the posttest and the retention test may indicate that the elderly switched between variables in these blocks, or that they relied on nonspecifying variables that we did not consider. In any case, and what is most important, contrary

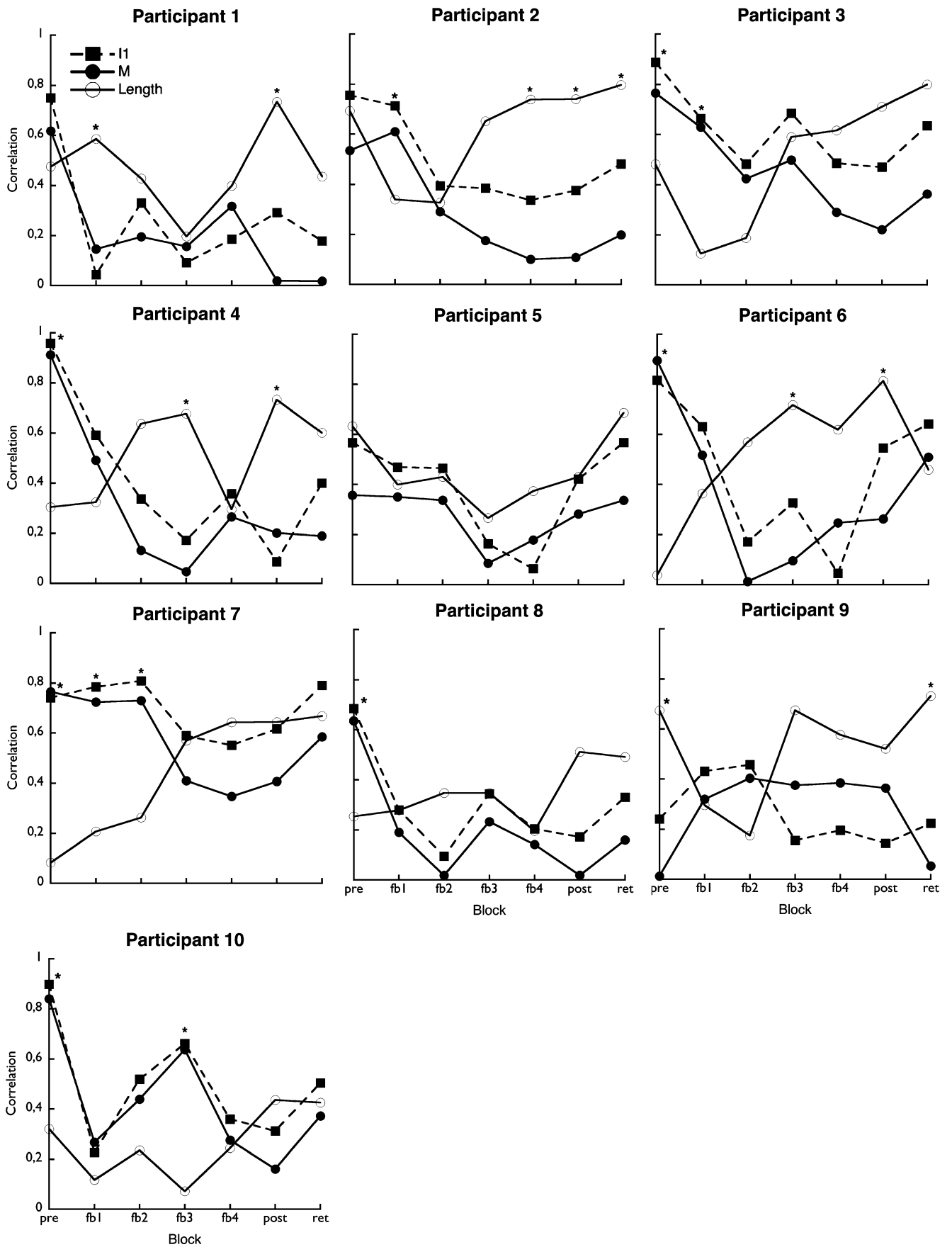
to the young adults, the elderly did not succeed in learning to detect a specifying variable over the course of the experiment.

As in earlier studies of perception, we also examined the individual performances (see e.g., Dicks, Davids, & Button, 2010; Jacobs et al., 2001; Menger & Withagen, 2009; Michaels & de Vries, 1998; Runeson & Andersson, 2007; Runeson, Juslin, & Olsson, 2000; Withagen & Michaels, 2005; Withagen & van Wermeskerken, 2009). As mentioned in the introduction, Withagen and van Wermeskerken observed substantial individual differences in learning to perceive length by dynamic touch. In our view, this finding suggests that any study on perceptual learning should also include analyses of individual performances. After all, such analyses are likely to provide a more detailed picture of the findings and to bring nuance to any observed group effect. To determine whether individual participants changed in what mechanical variable they exploited during the experiment, we analyzed for each individual and each phase the absolute correlation of perceived length with actual length and the candidate nonspecifying variables I_1 and M , using the logarithms of each of these variables. As in the previous analyses, we compared the correlation of perceived length and actual length with the correlation of perceived length and the most highly correlated nonspecifying variable. We performed a t test for dependent correlations (Bruning & Kintz, 1987) to find out whether the difference between these two correlations was significant (cf. Jacobs et al., 2001; Menger & Withagen, 2009; Withagen & Michaels, 2005; Withagen & van Wermeskerken, 2009). If the difference was significant, we concluded that the participant relied on a specifying or a nonspecifying variable (depending on which of the correlations was higher). After all, a significant difference implies that one variable explains the variation in perceived length significantly better than the other variable.

The individual results of the young adults are depicted in Fig. 3. Overall, the individual results are in

Fig. 2 The (absolute) correlations of perceived length and actual length, I_1 , and M in the pretest, posttest, and retention test. The left figure depicts the young adults, and the right figure the elderly. In the test phases marked with an *asterisk*, there is a significant difference ($p < .05$, two tailed) between the correlation of perceived length with actual length and the correlation of perceived length with the most highly correlated nonspecifying variable





◀ **Fig. 3** The (absolute) correlations between the length judgments and I_l , M , and actual length for the young adults: pretest (pre), feedback phases (fb1, fb2, fb3, fb4), the posttest (post), and the retention test (ret). In the blocks marked with an *asterisk*, there is a significant difference ($p < .05$, two tailed) between the correlation of perceived length with actual length and the correlation of perceived length with the most highly correlated nonspecifying variable

keeping with the result of the group analysis, but bring some nuance to it. Four of the 10 young adults succeeded in learning to detect the specifying variable—Participants 1, 2, 4, and 6 detected a specifying variable in at least two blocks. Participants 3 and 8 showed a nonsignificant trend to rely on a specifying variable. However, only one of these learners (Participant 2) detected a specifying variable in the retention test. This suggests that for many perceivers, attunement is not a relatively permanent effect. Instead, feedback seems required to maintain reliance on a specifying mechanical variable. Although Participants 5, 7, and 10 were affected by the feedback and changed their judgments, they did not discover a specifying variable. Participant 9 is arguably the most exceptional young adult. He detected a specifying variable in the pretest, which, to our knowledge, has been observed only once in the study of dynamic touch (Withagen & Michaels, 2005, Experiment 1, Participant 5). However, in the feedback blocks and the posttest, this participant did not reliably detect a specifying variable. Indeed, the correlation between perceived length and actual length seriously decreased in the first two feedback blocks. However, in the retention test, he returned to the detection of specifying information. For this participant, feedback seemed to be a disturbing factor, one that did not help him to improve his performance.

The individual results of the elderly are depicted in Fig. 4. As compared with the young adults, the elderly did not demonstrate considerable attunement effects. Only Participant 15 learned to detect a specifying variable during the experiment. However, all but one older adult (Participant 14) were affected by the feedback: They showed changes in their performances. Participants 12, 16, and 19 learned not to detect the nonspecifying variable they initially used. These participants all started with the exploitation of a nonspecifying variable but quickly learned not to use this variable. Also, in the retention test, they did not detect the variable they started with in the pretest. It might be that these participants switched between variables within the blocks or that they relied on a nonspecifying variable that we did not consider. Participants 11, 13, 17, and (to a lesser extent) 18, on the other hand, started and ended with the detection of nonspecifying information. Although these participants were all affected by the feedback, they did

not learn not to detect the nonspecifying variable they started with. Participant 17 is especially of interest. As mentioned earlier, we computed and reported the absolute correlations. However, in feedback blocks 3 and 4, the posttest, and the retention test, the high correlations between perceived length and I_l and M were negative for this participant. Apparently, this participant did not succeed in discovering the specifying variable in the first half of the experiment and adopted a new strategy in the rest of the experiment: The higher I_l and/or M , the shorter the rod. As far as we know, earlier studies have not found that perceivers adopt such a strategy. Participant 14, the oldest participant (81 years of age), was the only participant who was not affected by the feedback. During the whole experiment, this participant reliably detected a nonspecifying variable.

Discussion

The present experiments were conducted to test whether perceptual learning capacities degrade with aging. Both young adults and the elderly were trained to perceive length by dynamic touch. Earlier studies of aging and dynamic touch have found differences between undergraduates and older adults (Carello et al., 2000; Chang et al., 2008). However, these studies did not examine the capacity to learn a perceptual task. We found that the capacity to attune declines with aging. Averaged across participants, the young adults succeeded in learning to detect a specifying variable, whereas the elderly did not. Although the analyses of the individual results showed individual differences, they were in keeping with this general result: About half of the 10 young adults learned to detect a specifying mechanical variable, but only one of the nine older adults succeeded in doing so.

The remaining discussion consists of two sections. First, we will discuss the implications of our study for research on perception-action in elderly. We will end our article with addressing the consequences of our findings for recent discussions on the ecological theory of learning.

Aging and the capacity to learn

Over the last two decades or so, there has been an upsurge in studies of the perceptual-motor skills of elderly (e.g., Bock, 2005; Bock & Girgenrath, 2006; Fernández-Ruiz et al., 2000; Seidler, 2007). However, these studies have addressed mainly perceptual-motor recalibration. They exposed participants to visual distortions (often with prisms) and examined how they learn

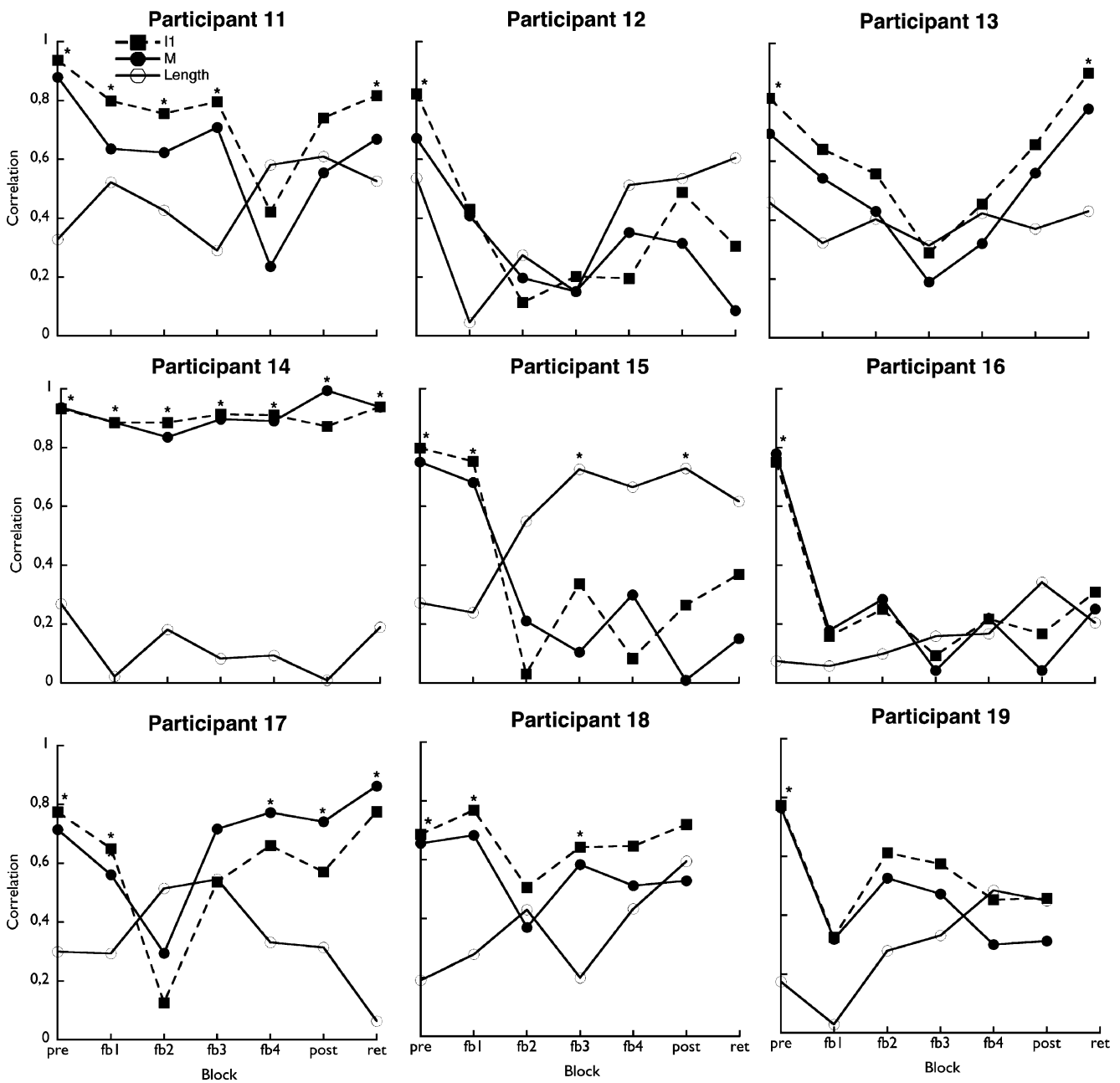


Fig. 4 The (absolute) correlations between the length judgments and I_1 , M , and actual length for the elderly: pretest (pre), feedback phases (fb1, fb2, fb3, fb4), the posttest (post), and the retention test (ret). In the blocks marked with an *asterisk*, there is a significant difference

($p < .05$, two tailed) between the correlation of perceived length with actual length and the correlation of perceived length with the most highly correlated nonspecifying variable. As mentioned earlier, Participants 18 and 19 did not perform the retention test

to behave adaptively again. That is, the focus was primarily on how the new realignment of the optical variables to the motor variables is established. This line of research has revealed interesting facts about the deterioration of the learning capacities when people grow older.

The present study, however, suggests that the examination of attunement should also be on the agenda in the research on elderly. After all, we found that the capacity to attune declines with aging. In general, the

elderly were not successful in learning to detect a mechanical variable that was specific to length. It is important to note that this process of attunement is not only relevant in this perceptual task, but that it is a prerequisite to behave adaptively in the natural environment. For actions to be coordinated with the environment, animals have to rely on variables that can appropriately guide their movements (see Michaels & Carello, 1981; Reed, 1996). In the ecological literature

on learning, there is a growing body of evidence indicating that, in many tasks, humans have to learn to rely on the useful informational patterns (e.g., Fajen, 2008; Fajen & Devaney, 2006; Jacobs et al., 2001, 2009; Kaye & van der Meer, 2000, 2007; Michaels & de Vries, 1998; Runeson & Andersson, 2007; van Hof, van der Kamp, & Savelsbergh, 2006). Hence, it would be interesting to examine whether the degradation of the capacity to attune can also be observed in these other paradigms. Such a demonstration would provide new insights into the observed perceptual-motor impairments of elderly.

Implications for the ecological theory of learning

The present study has also implications for the ongoing discussions on the ecological approach to learning (see e.g., Fajen, 2005; Jacobs & Michaels, 2007; Runeson et al., 2000; Withagen & van Wermeskerken, 2009). First, by conducting a retention test, we tested whether the learning effects are relatively permanent. As far as we know, this has not been examined before in the ecological study of learning. The effects of attunement proved not to be long lasting. Averaged over participants, the young adults reliably detected a specifying variable in the posttest, but failed to do so in the retention test. The analyses of the individuals revealed a similar result. Only one of the five participants (four young adults, one elderly) who learned to detect a specifying variable in the course of the experiment still used it in the retention test. The perceptual performances of the other learners declined. This suggests that a perceiver's discovery of the specifying information does not guarantee that this information is exploited from then on. Apparently, feedback is needed to maintain the detection of the most useful variable.

Second, the present study is also of interest for the discussions on how to account for variation in the use of perceptual variables. Thus far, the studies of variation have focused primarily on how environmental factors influence the use of perceptual variables. Cutting's (1986, 1991) *directed perception theory*, for instance, states that perceivers use different variables in different environmental or task contexts (see also Caljouw, van der Kamp, & Savelsbergh, 2004a, 2004b; Kingma et al., 2004; Tresilian, 1999). And studies of learning have focused mainly on how feedback and task ecologies determine the changes in performances (e.g., Jacobs & Michaels, 2007; Jacobs et al., 2001; Michaels & de Vries, 1998; Withagen & Michaels, 2005). However, based on an evolutionary analysis of perception, Withagen and Chemero (2009) suggested that organismal factors should also be taken into account in explaining variation in the use of perceptual variables. The main argument for their assertion is that in the course of evolution, natural selection is not likely to have eliminated all variation in the perceptual apparatuses

of members of the human species. This means that these apparatuses are likely to vary between perceivers. As mentioned in the introduction, earlier studies provided evidence for this statement by showing that the capacity to learn varies between participants (Menger & Withagen, 2009; Withagen & van Wermeskerken, 2009). However, the present study suggests that these capacities not only vary between perceivers but that they also evolve over time: The capacity to attune declines with aging. This proves once more that organismal factors are involved in determining how perceivers learn, and thus what perceptual variables they exploit.

At present, it is unclear what the degradation of the capacity to attune comprises. Menger and Withagen (2009) have proposed that the variation in attunement might be the result of two different factors.³ First, perceivers might vary in their ability to take advantage of feedback information. As argued by Runeson and colleagues (Runeson & Andersson, 2007; Runeson et al., 2000), the feedback error might be the result of noise in the perceptual system (Thurstonian error) or might occur because of the detection of a nonspecifying variable (Brunswikian error). Hence, for feedback to inform that a change in variable use is needed, a perceiver should be capable of distinguishing the Brunswikian error from the Thurstonian one. On the basis of their empirical findings, Withagen and van Wermeskerken (2009) surmised that perceivers vary in their capacity to do so. Second, perceivers might also vary in their ability to detect mechanical variables. It might be that the specifying mechanical variables are not easy to exploit and that perceivers vary in their ability to detect them. The present study suggests that mainly this latter capacity declines with aging. After all, the fact that all but one older adult changed their perceptual performances after feedback suggests that they were capable of taking advantage of the feedback information. They were informed by the feedback that they had to change in what mechanical variable they exploit. The absence of attunement effects in the elderly seems to be result of variation in the ability to detect mechanical variables. Older adults appear to have difficulty with discovering mechanical variables that are specific to length. However, explicit tests of these hypotheses await further development of the theory and the experimental program that can put it to a test.

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³ Margot van Wermeskerken introduced this distinction to Menger and Withagen (2009).

Appendix

Table 2 The geometric and mechanical properties of the rods used in the experiment

Material		length m	diameter M	m kg	M kg.m	I_1 kg.m ²	$I_3 \cdot 10^4$ kg.m ²
<i>Test rod set</i>							
1	Carbon	0.56	0.020	0.073	0.020	0.008	0.063
2	Carbon	0.76	0.020	0.099	0.038	0.019	0.086
3	Carbon	0.86	0.020	0.112	0.048	0.028	0.097
4	Carbon	0.96	0.020	0.125	0.060	0.039	0.108
5	Carbon	1.06	0.020	0.139	0.073	0.052	0.119
6	Aluminum	0.76	0.016	0.412	0.157	0.079	0.132
7	Steel	0.46	0.012	0.395	0.091	0.028	0.071
8	Steel	0.56	0.012	0.481	0.135	0.050	0.087
9	Wood	0.66	0.012	0.052	0.017	0.008	0.009
10	Wood	0.86	0.012	0.068	0.029	0.017	0.012
11	Steel	0.46	0.008	0.176	0.040	0.012	0.014
12	Steel	0.56	0.008	0.214	0.060	0.022	0.017
13	Steel	0.66	0.008	0.252	0.083	0.037	0.020
<i>Feedback rod set</i>							
1	Carbon	0.71	0.020	0.093	0.033	0.016	0.080
2	Carbon	0.91	0.020	0.119	0.054	0.033	0.102
3	Carbon	1.01	0.020	0.132	0.067	0.045	0.114
4	Carbon	1.11	0.020	0.145	0.081	0.060	0.125
5	Carbon	1.21	0.020	0.158	0.096	0.077	0.136
6	Aluminum	0.91	0.016	0.494	0.225	0.136	0.158
7	Steel	0.61	0.012	0.524	0.160	0.065	0.094
8	Steel	0.71	0.012	0.610	0.217	0.102	0.110
9	Wood	0.81	0.012	0.064	0.026	0.014	0.012
10	Wood	1.01	0.012	0.080	0.040	0.027	0.014
11	Steel	0.61	0.008	0.232	0.071	0.029	0.019
12	Steel	0.71	0.008	0.271	0.096	0.046	0.022
13	Steel	0.81	0.008	0.309	0.125	0.068	0.025

References

- Arzamanski, R., Isenhower, R. W., Kay, B. A., Turvey, M. T., & Michaels, C. F. (2010). Effects of intention and learning on attention to information in dynamic touch. *Attention, Perception, & Psychophysics*, *72*, 721–735.
- Bock, O. (2005). Components of sensorimotor adaptation in young and elderly subjects. *Experimental Brain Research*, *160*, 259–263.
- Bock, O., & Girgenrath, M. (2006). Relationship between sensorimotor adaptation and cognitive functions in younger and older subjects. *Experimental Brain Research*, *160*, 400–406.
- Bruning, J. L., & Kintz, B. L. (1987). *Computational handbook of statistics* (3rd ed.). Glenview, IL: Scott-Foresman.
- Cabe, P. A. (2010). Sufficiency of longitudinal moment of inertia for haptic cylinder length judgments. *Journal of Experimental Psychology: Human Perception and Performance*, *36*, 373–394.
- Caljouw, S., Van der Kamp, J., & Savelsbergh, G. J. P. (2004a). The fallacious assumption of time-to-contact perception in the regulation of catching and hitting. In H. Hecht & G. J. P. Savelsbergh (Eds.), *Theories of time-to-contact: Advances in psychology 135* (pp. 443–474). Amsterdam: Elsevier.
- Caljouw, S. R., Van der Kamp, J., & Savelsbergh, G. J. P. (2004b). Catching optical information for the regulation of timing. *Experimental Brain Research*, *155*, 427–438.
- Carello, C., & Turvey, M. T. (2004). Physics and psychology of the muscle sense. *Current Directions in Psychological Science*, *13*, 25–28.
- Carello, C., Thuot, S., & Turvey, M. T. (2000). Aging and the perception of a racket's sweet spot. *Human Movement Science*, *19*, 1–20.
- Chang, C.-H., Wade, M. G., Stoffregen, T. A., & Ho, H.-Y. (2008). Length perception by dynamic touch: The effects of aging and experience. *Journal of Gerontology: Psychological Science*, *63b*, 165–170.
- Cutting, J. E. (1986). *Perception with an eye for motion*. Cambridge, MA: MIT Press.
- Cutting, J. E. (1991). Four ways to reject directed perception. *Ecological Psychology*, *6*, 185–204.

- Dicks, M., Davids, K., & Button, C. (2010). Individual differences in the visual control of intercepting a penalty kick in association football. *Human Movement Science*, *29*, 401–411.
- Fajen, B. R. (2005). Perceiving possibilities for action: On the necessity of calibration and perceptual learning for the visual guidance of action. *Perception*, *6*, 717–740.
- Fajen, B. R. (2008). Perceptual learning and the visual control of braking. *Perception & Psychophysics*, *70*, 1117–1129.
- Fajen, B. R., & Devaney, M. C. (2006). Learning to control collisions: The role of perceptual attunement and action boundaries. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 300–313.
- Fernández-Ruiz, J., Hall, C., Vergara, P., & Díaz, R. (2000). Prism adaptation in normal aging: Slower adaptation rate and larger aftereffect. *Cognitive Brain Research*, *9*, 223–226.
- Gibson, J. J., & Gibson, E. J. (1955). Perceptual learning: Differentiation or enrichment? *Psychological Review*, *62*, 32–41.
- Jacobs, D. M., & Michaels, C. F. (2007). Direct learning. *Ecological Psychology*, *19*, 321–349.
- Jacobs, D. M., Runeson, S., & Michaels, C. F. (2001). Learning to perceive the relative mass of colliding balls in globally and locally constrained task ecologies. *Journal of Experimental Psychology: Human Perception and Performance*, *27*, 1019–1038.
- Jacobs, D. M., Silva, P. L., & Calvo, J. (2009). An empirical illustration and formalization of the theory of direct learning: The muscle-based perception of kinetic properties. *Ecological Psychology*, *21*, 245–289.
- Kayed, N. S., & van der Meer, A. L. H. (2000). Timing strategies used in defensive blinking to optical collisions in 5-to 7-month-old infants. *Infant Behavior & Development*, *23*, 253–270.
- Kayed, N. S., & van der Meer, A. L. H. (2007). Infants' timing strategies to optical collisions: A longitudinal study. *Infant Behavior & Development*, *30*, 50–59.
- Kenshalo, D. R. (1986). Somesthetic sensitivity in young and elderly humans. *Journal of Gerontology*, *41*, 732–742.
- Kingma, I., van de Langenberg, R., & Beek, P. J. (2004). Which mechanical invariants are associated with the perception of length and heaviness of a nonvisible handheld rod? Testing the inertia tensor hypothesis. *Journal of Experimental Psychology: Human Perception and Performance*, *30*, 346–354.
- Menger, R., & Withagen, R. (2009). How mechanical context and feedback jointly determine the use of mechanical variables in length perception by dynamic touch. *Attention, Perception, & Psychophysics*, *71*, 1862–1875.
- Michaels, C. F., Arzamarski, R., Isenhower, R. W., & Jacobs, D. M. (2008). Direct learning in dynamic touch. *Journal of Experimental Psychology: Human Perception and Performance*, *34*, 944–957.
- Michaels, C. F., & Carello, C. (1981). *Direct perception*. Englewood Cliffs, NJ: Prentice Hall.
- Michaels, C. F., & de Vries, M. M. (1998). Higher order and lower order variables in the visual perception of relative pulling force. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 526–546.
- Michaels, C. F., Weier, Z., & Harrison, S. J. (2007). Using vision and dynamic touch to perceive the affordances of tools. *Perception*, *36*, 750–772.
- Reed, E. S. (1996). *Encountering the world: Toward an ecological psychology*. New York, NY: Oxford University Press.
- Riley, M. A., Wagman, J. B., Santana, M., Carello, C., & Turvey, M. T. (2002). Perceptual behavior: Recurrence analysis of a haptic exploratory procedure. *Perception*, *31*, 481–510.
- Runeson, S., & Andersson, I. E. K. (2007). Achievement of specificational information usage with true and false feedback in learning a visual relative-mass discrimination task. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 163–182.
- Runeson, S., Juslin, P., & Olsson, H. (2000). Visual perception of dynamic properties: Cue heuristic versus direct-perceptual competence. *Psychological Review*, *107*, 525–555.
- Seidler, R. D. (2007). Older adults can learn new motor skills. *Behavioural Brain Research*, *183*, 118–122.
- Solomon, H. Y., & Turvey, M. T. (1988). Haptically perceiving the distance reachable with hand-held objects. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 404–427.
- Stephen, D. G., & Arzamarski, R. (2009). Self-training of dynamic touch: Striking improves judgment by wielding. *Attention, Perception, & Psychophysics*, *71*, 1717–1723.
- Stevens, J. C. (1992). Aging and the spatial acuity of touch. *Journal of Gerontology*, *47*, 35–40.
- Tresilian, J. R. (1999). Visually timed action: Time-out for 'tau'. *Trends in Cognitive Sciences*, *3*, 301–310.
- Turvey, M. T. (1996). Dynamic touch. *The American Psychologist*, *51*, 1134–1152.
- Turvey, M. T., & Carello, C. (1995). Dynamic touch. In W. Epstein & S. Rogers (Eds.), *Handbook of perception and cognition: Perception of space and motion* (pp. 401–490). New York, NY: Academic.
- Van de Langenberg, R., Kingma, I., & Beek, P. J. (2006). Mechanical invariants are implicated in dynamic touch as a function of their saliency in the stimulus flow. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 1093–1106.
- Van Hof, P., van der Kamp, J., & Savelsbergh, G. J. P. (2006). Three-to eight-month-old infants' catching under monocular and binocular vision. *Human Movement Science*, *25*, 18–36.
- Wagman, J. B., & Carello, C. (2003). Haptically creating affordances: The user-tool interface. *Journal of Experimental Psychology: Applied*, *9*, 175–186.
- Wagman, J. B., Shockley, K., Riley, M. A., & Turvey, M. T. (2001). Attunement, calibration, and exploration in fast haptic perceptual learning. *Journal of Motor Behavior*, *33*, 323–327.
- Withagen, R., & Michaels, C. F. (2005). The role of feedback information for calibration and attunement in perceiving length by dynamic touch. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 1379–1390.
- Withagen, R., & Chemero, A. (2009). Naturalizing perception: Developing the Gibsonian approach to perception along evolutionary lines. *Theory & Psychology*, *19*, 363–389.
- Withagen, R., & van Wermeskerken, M. (2009). Individual differences in learning to perceive length by dynamic touch: Evidence for variation in perceptual learning capacities. *Attention, Perception, & Psychophysics*, *71*, 64–75.
- Withagen, R., & van der Kamp, J. (2010). Towards a new ecological conception of perceptual information: Lessons from a developmental systems perspective. *Human Movement Science*, *29*, 149–163.